LCA Methodology with Case Study

Using LCA to Examine Greenhouse Gas Abatement Policy

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Abstract. The site-generic approach currently adopted by the Life Cycle Assessment (LCA) methodology introduces uncertainties into the impact assessment phase of an LCA study. These uncertainties are greatest for localised and short-lived problems but are less significant for long lasting, cumulative environmental effects. Indeed, the reliability of LCA results is high for problems that manifest at a global scale. Nevertheless, even though these results are considered accurate, it is still often unclear as to their relevance in terms of policy development and decision-making. Therefore, this paper demonstrates how LCA can be used to determine the efficacy of policies aimed at reducing a product system's contribution to global environmental problems.
We accomplish this aim by presenting a case study that evaluates the greenhouse gas contributions of each stage in the life cycle of containerboard packaging and the potential impact on emissions of various policy options available to decision makers. Our analysis showed that in general the most useful strategy was to recycle the used packaging. However, our analysis also indicated that when measures are taken to eliminate sources of methane emissions and encourage the use of plantation timber then recycling is no longer beneficial from a greenhouse perspective. This is because the process energy required in the form of gas and electricity is substantially greater for containerboard manufactured from recycled material than it is for virgin fibre.

Keywords: Containerboard; greenhouse gas abatement policy; ISO 14040; life cycle assessment; packaging; pulp and paper; uncertainty

Introduction

The lack of site-specific data in the life cycle inventory and the implications of this for the reliability and relevance of conclusions made during life cycle impact assessment continue to be debated within the Life Cycle Assessment (LCA) community [1–12]. Some of the strongest criticism has come from Owens [1–3], who argues that without this additional site-specific data, significant sources of uncertainty are introduced into the impact assessment phase of the LCA, and White et al. [4], who argue that the current 'less is better' approach, which calculates global parameters for impact categories by aggregating data across the whole life cycle, assumes a worst-case scenario that could "misguide improvement measures or policy-making." Others, such as Klöpffer [5], point out that the emissions established in the inventory analysis are expressed in amounts per functional unit and in principle, nothing is known about the source-strength and variation over time of the examined processes. Moreover, the standardized approach employed by LCA is to present the results in terms of aggregated global contributions that ignore the origin and time of the emissions [6]. This is problematic because it limits the range of effects that can be accurately assessed by LCA to those that are global and long lasting [1]. For example, greenhouse gases emitted by product systems anywhere in the world contribute to the same global effect – but this is only true for effects that manifest at a global scale. For non-global environmental effects, site-specific information is needed to determine whether an emission from a particular source makes a significant contribution to these problems [13–15].

Thus, it is not surprising that industry has expressed concerns about the relevance of LCA results [16]. Indeed, the pressure to cut corners and generate conclusions of value to the client has meant that many studies have been criticized for making claims that cannot be justified by the results [17]. These criticisms have not only damaged the technique's credibility but they have led some people to question whether LCA has anything of real value to contribute to environmental assessment. Therefore, the aim of this paper is to demonstrate that LCA can produce results that are relevant to the development and implementation of policy strategies designed to minimise the environmental burden resulting from the provision of services or the manufacture, use and disposal of products within the economy.

We achieve this aim by presenting a case study of the production of containerboard packaging that illustrates how LCA can be used to formulate policy that reduces the environmental burden of products and services within the economy. In this example we use LCA to assess policies designed to reduce greenhouse gas (GHG) emissions from the pulp and paper industry in Australia.

1 The Greenhouse Problem

The release of large quantities of carbon dioxide, methane, chlorofluorocarbons and other gases into the atmosphere is hypothesised to cause a relatively rapid rise in mean global

temperature [18]. The first significant step towards tackling this problem came in the form of a global treaty signed in Kyoto in 1997. Nations defined under Annex 1 have committed to stabilising their GHG emissions to approximately 1990 levels by 2010. To meet their commitments, governments have in the first instance tried to encourage the adoption of more energy-efficient practices by industry and the community. However, it is increasingly evident that for some nations, increased energy efficiency alone will be insufficient to achieve their GHG emission targets, so more interventionist policy measures may be needed.

Industry is also conscious of the growing pressure to reduce GHG emissions, and many of the large polluters are investigating ways to reduce their contributions. One problem with choosing an appropriate abatement strategy is that greenhouse gas emissions can occur at different stages of the manufacture, use and disposal of a product or the execution of an activity that might not be at all obvious [19]. For example, our case study involves various decisions at various stages in the product life that affect the quantity of greenhouse gases emitted into the atmosphere:

- When growing the trees to make the wood pulp required, what difference does replanting make?
- What effect does recycling of the used containerboard have?
- How critical is the effect of transportation of the timber from forest to factory and used containerboard to recycling facilities or disposal sites?
- How important is the method of disposal at the end of the packaging's life?

Industry groups involved in only one life cycle stage of a product or activity might therefore implement counterproductive measures in their efforts to reduce emissions. If governments decide that voluntary industry programs are not working they might start to introduce regulations or taxation regimes on products or activities to produce greater reductions. To properly understand the full implications of regulatory and fiscal approaches, governments also must have a complete picture of the process or activity, rather than a partial one. This is where LCA has a considerable advantage over other environmental impact assessment methods, because it employs a systems-based approach, which ensures that all of the potential contributions to the greenhouse effect of the manufacture, use and disposal of containerboard are accounted for in the final analysis.

2 Case Study: Containerboard Packaging

Before we can answer questions about the benefits of a particular greenhouse gas abatement strategy, it is necessary to quantify the material, energy and finally the GHG emissions of each step in the life cycle to identify the greenhouse 'hotspots', and then examine the changes in GHG emissions resulting from the introduction of various abatement policies.

2.1 The manufacture of containerboard

Containerboard is made by gluing fluted cardboard between two liners or flat layers. The first step in making containerboard is the procurement of feedstock material as input to the pulping process from either the harvesting of trees from naturally occurring and cultivated forests or the collection of used paper and cardboard from the economy. The choice of pulping process depends on the type of raw material, and the required properties of the containerboard. In Australia, processes fall into two major groups: chemical pulping, which is used for wood fibre and mechanical pulping, which is used for recycled material.

In chemical pulping the wood is treated with chemicals that dissolve the lignin and leave the cellulose behind. This cellulose forms the pulp that is used to make cardboard or paper. The yield of cellulose is about half the original mass of the wood. It follows that around half of the calorific value of the original wood is rejected in the lignin waste stream. This energy is recovered by concentrating this waste stream to form 'black liquor', which is burnt in boilers to produce electricity and steam. These provide the process energy for the pulper and the subsequent manufacture of cardboard.

In mechanical pulping the recycled material is broken up solely by heating and mechanical beating. Thus the yield of pulp is higher, but its properties are affected by the deterioration in the quality of the cellulose fibres caused by continual recycling. In practice, this sets an upper limit to the recycling rate. We were told by Visy Board, an Australian paper recycler, that fibre for containerboard should not be recycled more than four times. As the lignin is not available to provide process energy, this has to be provided by energy brought in in other forms. Moreover, the energy requirement is rather high because of the large amount electricity used during mechanical beating.

The pulp is converted into smooth liner-board for the inner and outer layers of the sandwich, and corrugated fluted-board for the middle layer. These layers are then stuck together by starch glues, and the resulting containerboard is cut and preformed into blanks ready for assembly. These blanks are transported to the customer where they are folded, and in some cases glued, to be used as packaging for manufactured products. In this form it is transported to the retail outlet, where the product is purchased by the consumer. The empty packaging will either find its way to landfill or back to a pulping plant for recycling.

In the Australian state of Victoria the two processes are typified by the mills run by Amcor Ltd and Visy Board Pty Ltd. Amcor has access to its own plantations, and predominantly uses chemical pulping to produce a high quality containerboard from chemical pulp using almost 100 per cent virgin wood as feedstock. Visy Board makes containerboard from 100 per cent recycled paper and cardboard, using mechanical pulping. We decided to analyse both these processes because they represent the two extreme alternatives of the product system.

2.2 Data sources

As we did not have access to detailed information on materials flows or energy requirements for either process, we had to adapt overseas data to Australian conditions. Energy requirements for the harvesting of wood and the operation of the pulping

and containerboard processes were taken from a Swedish lifecycle study [20]. Although Amcor and Visy Board were unable to provide data, they agreed that containerboard production processes were not likely to differ greatly from country to country. Energy and material requirements for the operation of oil wells, gas wells, oil refineries and gas separation plants were either supplied by Broken Hill Pty Ltd. or taken from the work of Boustead [21]. The energy requirements for making the requisite electricity were modified to accord with the technology mix for electricity production in the state of Victoria. Transport energy for the delivery of lumber and packaging was calculated for Australian conditions from performance data reported in a Swiss lifecycle study [22]. The energy required to construct equipment was estimated from indicative costs of the various pieces of equipment provided by Amcor and Visy Board, and the energy intensity for that type of equipment in MJ per dollar. The method is rather crude, but, as we will see later, it is better to make a reasonable estimate of this energy than to entirely ignore it, as is the custom in most life cycle assessments [23]. We did not include the material and energy inputs and outputs for the maintenance of plantation timber or the production of the chemicals and starch because accurate data for these aspects of the system was unavailable. However, in practice, these quantities are small when compared to the main system processes and do not make a significant contribution to the aggregated results.

2.3 System boundaries for the life cycle of containerboard packaging

Fig. 1 is a simplified systems diagram for the packaging life cycle. The functional unit for this system is 1 kg of usable containerboard packaging. The moisture content of containerboard is approximately 12.5% by weight so 0.88 kg of dry containerboard equates to 1 kg of usable moist containerboard. This system diagram combines the virgin-based manufacturing approach that uses chemical pulping of virgin logs, as typified by the process used by Amcor, with the recycling-based manufacturing approach that uses mechanical pulping of recycled material, as typified by the process used by Visy Board. In this simple closed-loop recycling system, the allocation rules assume that all containerboard collected at the 'kerbside' is recycled back into new containerboard packaging by Visy Board [24–25]. Thus, recycling decreases the demand for virgin fibre and reduces the quantity of used packaging going to landfill.

In Fig. 1 the feedstock to the mechanical pulper is material recycled from within the economy rather than drawn from the natural environment. In chemical pulping the waste is burnt to raise energy but the waste from the mechanical pulper is unsuitable for this purpose, and is sent to landfill.

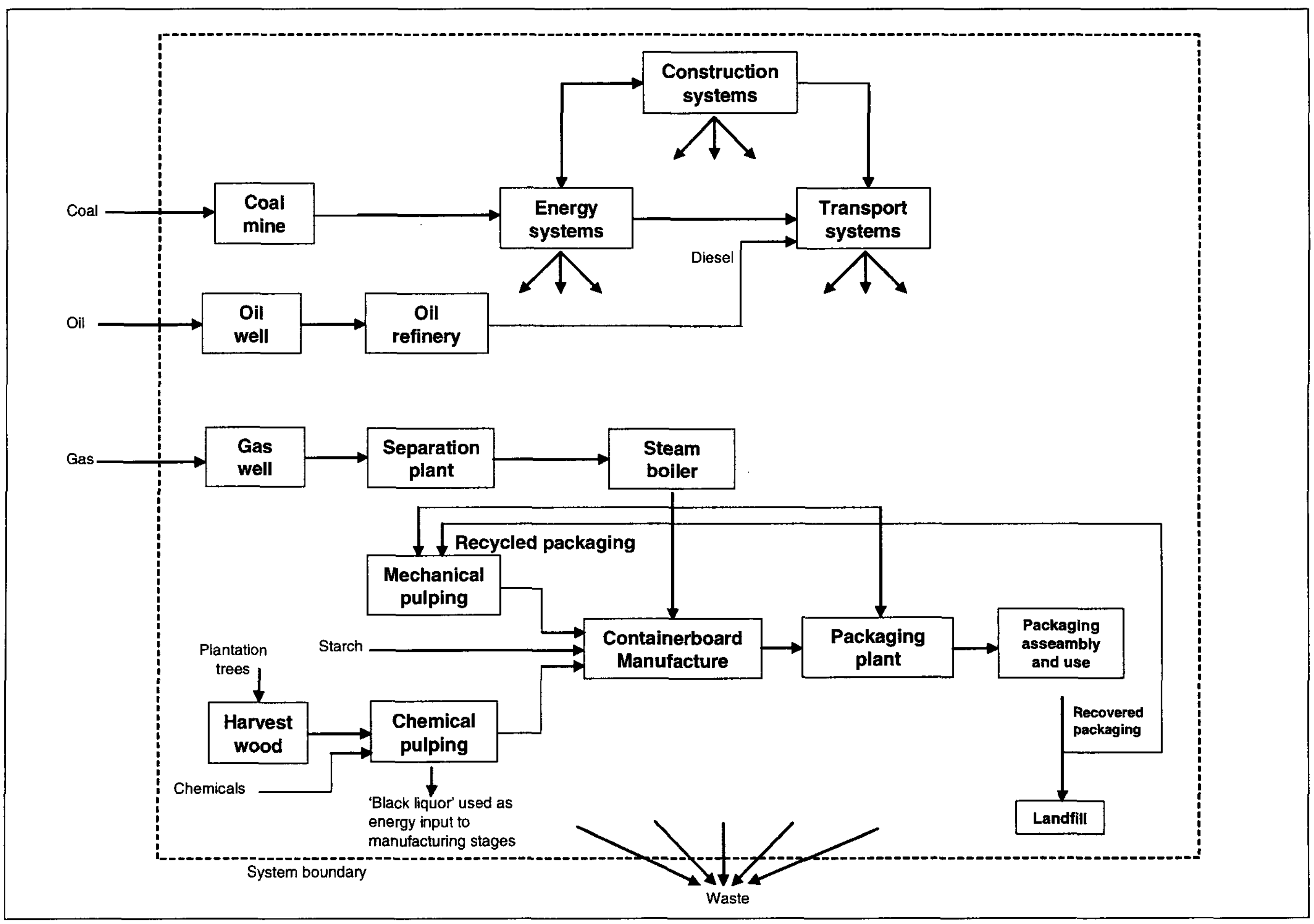

Fig. 1: Life cycle system diagram for the production of 1 kg of containerboard packaging in Australia

2.4 Greenhouse gas emissions across the life cycle of containerboard packaging

The only greenhouse gas emissions of any significance in the manufacture and use of containerboard packaging are carbon dioxide and methane. We can calculate the amount of carbon dioxide emitted from the combustion of the primary energy inputs as fossil fuels. However, the assumptions about credits and debits for containerboard are quite controversial. Therefore, we have to be careful to make our assumptions clear, and to test the effects of making different assumptions.

2.4.1 Absorption of carbon dioxide from the atmosphere during photosynthesis

The first problem concerns the absorption of carbon dioxide by growing trees. The logs used to make containerboard have come from trees that have in the past absorbed carbon dioxide from the atmosphere and converted it to plant tissue by photosynthesis. When the trees are harvested, branches and leaves are left in the forest. These are oxidized in the air with the help of insects, fungi and bacteria, liberating their share of carbon dioxide back into the atmosphere. If the logs are chemically pulped, the lignin will be burnt, liberating carbon dioxide, leaving only the cellulose for making containerboard. After use, some of this containerboard packaging may be burnt, some will go to landfills where it may decompose, and some of it will be recycled.

If trees are replanted to replace those that have been felled, the new trees will begin to photosynthesize, and absorb carbon dioxide from the atmosphere. This process will continue over many years, until the trees reach their mature state. Thus we have a continuous cycling of carbon dioxide to and from the atmosphere. Although the time scales are different for the various processes involved, we may imagine a situation in which the containerboard manufacturer is operating plantations on a steady and sustained basis to provide a new supply of logs at precisely the rate at which they are being used. The rate of absorption of carbon dioxide will then be exactly the same as the rate of emission (assuming the material sent to landfills also ends up as carbon dioxide – not necessarily a good assumption, as we shall discuss shortly). This simplification may also be optimistic in light of recent work on old growth forests that suggest that the sequestration and release of carbon is far more complicated than we have made it out to be [26]. But for the moment let us assume this is so: then the net emission from trees will be zero kg of carbon dioxide per kg of containerboard packaging.

2.4.2 Anaerobic decomposition of containerboard in landfill

The second problem concerns the fate of containerboard disposed of in a landfill. Organic material, including the cellulose in containerboard, will decompose under the influence of moulds and bacteria. In landfills any oxygen present from the air will be quickly used up, and further decomposition will be anaerobic, liberating oxygen-deficient gases such as methane, ammonia and hydrogen sulphide. As seen from the following chemical equation, the carbon atoms in cellulose are assumed to yield equal numbers of carbon dioxide and methane molecules:

$$\text{-}CH_2O\text{-}CH_2O\text{-}^{a} \rightarrow CO_2 + CH_4$$

a: Strictly speaking, CH_2O is not the true molecular formula for cellulose. However, this simplification is a reasonable approximation and does not greatly compromise the accuracy of the results.

This decomposition is caused by anaerobic bacteria seeking energy for their metabolism. Rain water percolating through the landfill provides the moisture the bacteria need to survive. It is possible to design landfills with good drainage to minimize the decomposition of cellulose. Containerboard could take many years to decompose in such landfills. However, it would eventually do so, and the greenhouse effect itself will build up over many years. Therefore, in our calculations for the base case we shall assume that the carbon atoms in any containerboard or cellulosic waste sent to landfill will be emitted half as carbon dioxide and half as methane.

2.4.3 Recycling

For the base case we have assumed that for the virgin process, all containerboard is eventually disposed to landfill whereas for the recycling process, containerboard is recycled continuously. Though, as we will discuss later, this is unrealistic for several reasons, we have chosen this scenario because it represents the most extreme case in a whole spectrum of system possibilities, which we will explore later.

2.5 Relative contribution of the various stages

Using these assumptions, we can now calculate the emissions of greenhouse gases as carbon dioxide equivalents for containerboard packaging made from wood using a chemical pulping process and recycled material using a mechanical pulping process. The results are shown in **Fig. 2**.

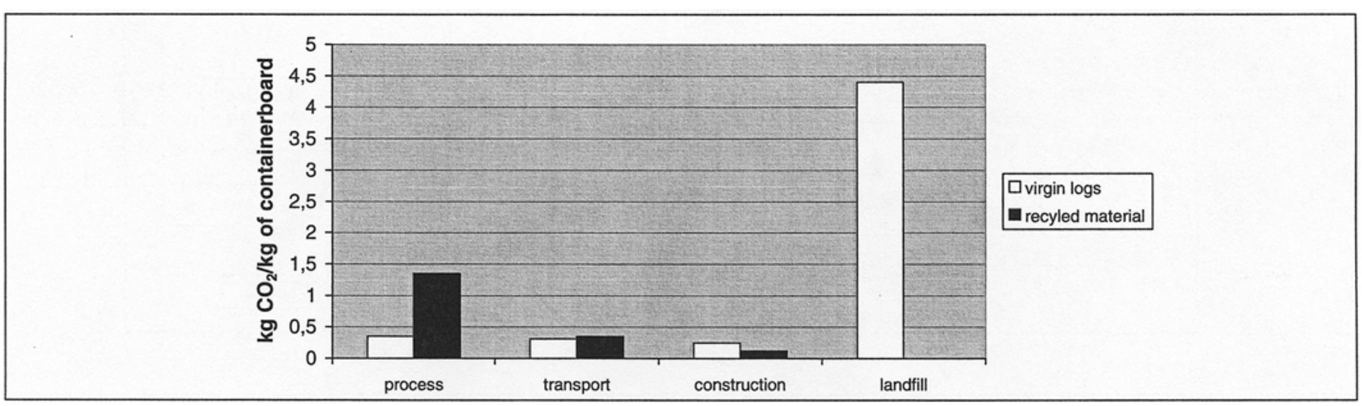

Fig. 2: Emissions of greenhouse gases in kg of carbon dioxide per kg of containerboard packaging for the two processes

In the base-case analysis shown in Fig. 2, the GHG emissions for the use of packaging made from the chemical pulping of virgin logs are far greater than those for the use of recycled material. The reason for this is the very large contribution from methane liberated during the anaerobic decomposition of the discarded packaging in landfill. For packaging made from continually recycled material this does not occur, and the largest contribution is from the pulping process. This is due to the large amount of electricity used in mechanical pulping. In both cases the contribution to the emissions from the use of transport energy is relatively small. In fact, it is of the same order as the contribution from construction energy, which most analysts ignore.

A number of assumptions were made when carrying out this base-case analysis. We will now investigate the sensitivity of our results to changes in these assumptions.

2.6 The effect on GHG emissions of modifying the assumptions

The base assumptions for the manufacture, use and disposal of containerboard packaging were:

1. All the wood used for the original manufacture of containerboard, irrespective of the degree of recycling, came originally from constantly renewed plantations, i.e. there was no net depletion of forests;
2. All the containerboard disposed of to landfill decomposes anaerobically, with half the carbon atoms in it forming methane, and half forming carbon dioxide;
3. No containerboard produced using chemical pulping of wood from forests was recycled; all was disposed of to landfill.

Clearly, there could be circumstances where one or more of these assumptions do not hold. We will now set up an equation for calculating the effects of these assumptions on the emission of greenhouse gases. To do this, we have to modify the base assumptions.

2.6.1 Plantations

First, the packaging could be made from trees that are cut down and not replanted; for example the land could be converted to grazing or agriculture. In this case we would have to assume that all the carbon in the trees would eventually be liberated into the atmosphere, and that, in contrast to the regrowth of trees in plantations, there would be no offsetting absorption due to photosynthesis. The actual situation for any given mill or any given economy could lie somewhere between these two extremes. To take account of this possibility, we will assume that a proportion P of the wood for manufacturing containerboard comes from continuously renewed plantations, and a proportion (1-P) comes from depleting forests.

2.6.2 Decomposition of waste containerboard

Our second base-case assumption is that any containerboard or cellulosic waste sent to landfill would decompose anaerobically, and half the carbon atoms in it would be emitted as carbon dioxide and half as methane.

However, in some landfills methane is being collected and burnt as a fuel. In this way its energy content is recovered, and the methane is converted into carbon dioxide, which has a far smaller global warming potential than methane. Another possibility is that waste containerboard could be burnt or composted aerobically, instead of being sent to landfill, thus converting it completely to carbon dioxide.

To take account of these possibilities, we now assume that of the containerboard rejected to landfill, a proportion *A* is decomposed anaerobically, with half the carbon atoms in this proportion going to methane and half to carbon dioxide. A proportion *(1-A)* is decomposed by aerobic decomposition, incineration or anaerobic decomposition followed by combustion of the methane formed, with all the carbon atoms going to carbon dioxide.

2.6.3 Recycling

Finally, we have assumed that all the containerboard from chemical pulping is being rejected to landfill, and none is being recycled. This is unrealistic: even if all used containerboard was sent to landfill, material must be recycled from other activities elsewhere in the economy to provide feedstock for the Visy Board plant. Similarly, even though the Visy Board process uses recycled paper and containerboard, a proportion of the originally harvested wood ends up as waste paper and containerboard disposed of to landfill (this is, of course, the proportion *not* being recycled).

In the economy as a whole, a proportion *R* of the containerboard is recycled by mechanical pulping, and a proportion *(1-R)* comes from chemical pulping of virgin wood. The two principal components of wood are lignin and cellulose. In chemical pulping the desired product is the cellulose, and the lignin is separated off as a waste product. All of this lignin is burnt to provide energy for the chemical pulping and the containerboard manufacturing processes, and the carbon atoms in it are thus converted to carbon dioxide. Approximately half of the wood may be considered to be cellulose and half lignin. The actual figures vary from wood to wood, but for the present purposes this assumption will serve well enough. The chemical composition of cellulose is taken to be $[CH_2O]_n$.

2.6.4 Setting up the equation

Using these assumptions, we can set up a carbon flow diagram as shown in **Fig. 3**. The whole of the system is surrounded by a boundary line, which represents the boundary between it and the atmosphere. Thus, arrows crossing this boundary represent flows of carbon into and out of the atmosphere as carbon dioxide or methane. Note that no carbon dioxide is being absorbed by photosynthesis in the depleting forest, as the wood that is being used up is not being replaced by new growth. Streams within the system boundary are not marked with a chemical species as they are either cellulose or containerboard, which are assumed to have the chemical composition $[CH_2O]_n$.

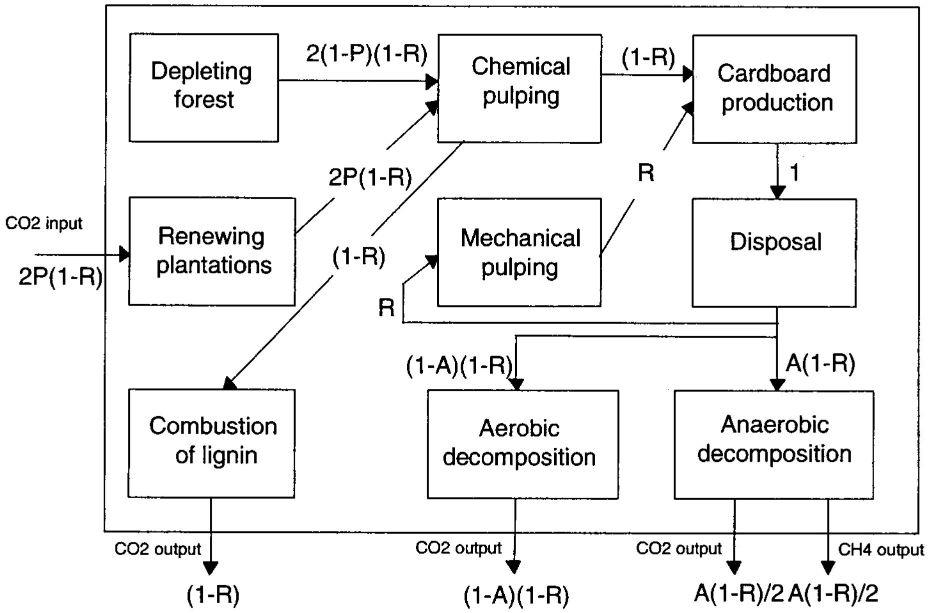

Fig. 3: Flows of carbon atoms during the transformation of feedstock in the production and disposal of containerboard

All flows are labelled with algebraic expressions representing atoms of carbon. Note that with the exception of the depleting forest, a carbon balance on every unit process gives no net gain or loss of carbon, as expected.

As shown in **Table 1**, by subtracting the absorption of carbon atoms as carbon dioxide by photosynthesis from the emission of carbon atoms as carbon dioxide or methane, we obtain the net emission of carbon atoms to the atmosphere as 2(1-P)(1-R) atoms per molecule of containerboard. Note that when P = 1, i.e. all containerboard comes from renewing plantations, the net emission becomes zero, as expected. Similarly, when R = 1, i.e. all containerboard is obtained from recycling within the economy, the net emission of carbon atoms is again zero, as no containerboard is decomposing in landfill and, as no trees are being grown for containerboard, no lignin is being burnt.

This net emission is based on carbon atoms. In practice we are interested in kg of various species such as cellulose, carbon dioxide and methane. We can convert to kg of the various species by multiplying by their molecular weights: 30 for cellulose; 16 for methane; and 44 for carbon dioxide. Therefore, to bring the above tabulation to the basis of 1 kg of moist containerboard or 0.88 kg of dry containerboard we have to multiply methane figures by 0.88 x 16/30 and carbon dioxide figures by 0.88 x 44/30. Finally, to bring the methane figures to CO_2 greenhouse equivalents, we have to multiply the kg of methane by 21.5 [27]. Applying all of these factors, Table 1 gives net emissions in kg of CO_2 equivalents per kg of moist containerboard as:

Emissions from the use of feedstock = (1-R)(4.40A + 2.58 – 2.58P)

To this we must add R times the emissions due to the transport energy, construction energy and process energy used for mechanical pulping of recycled containerboard, containerboard manufacture and the use of the packaging, plus (1-R) times the emissions for the transport, construc-

Table 1: Sources of carbon atoms in the production and disposal of containerboard

Process emissions	Carbon	Proportion of C atoms	Equivalent amounts of CO_2 per kg of containerboard
Combustion of lignin to produce energy for virgin processes	CO_2 emitted	(1-R)(1)	0.88*44/30*(1-R)(1)
Aerobic decomposition from incineration, methane capture, etc.	CO_2 emitted	(1-R)(1-A)	0.88*44/30*(1-R)(1-A)
Anaerobic decomposition in landfill	CO_2 emitted	(1-R)(A/2)	0.88*44/30*(1-R)(A/2))
Anaerobic decomposition in landfill	CH_4 emitted	(1-R)(A/2)	0.88*16/30*21.5*(1-R)(A/2)
Photosynthesis occurring in renewing plantations	CO_2 absorbed	(1-R)(2P)	0.88*44/30*(1-R)(2P)
Totals		**(1-R)(2-2P)**	**(1-R)(4.40A+2.58-2.58P)**

tion and process energy used for chemical pulping of virgin material, containerboard manufacture and the use and disposal of the packaging. These two together total 0.91 + 0.92R kg of carbon dioxide equivalents per kg of moist containerboard packaging. This gives the following equation for the total emissions:

$$\text{Total emissions} = (0.91 + 0.92R) + (1\text{-}R)(4.40A + 2.58 - 2.58P)$$

where

- R is the proportion of containerboard recycled inside the economy;
- P is the proportion of original feedstock from plantations;
- A is the proportion of landfilled containerboard waste undergoing anaerobic decomposition.

Recycling reduces emissions because of its effect on the second term of the right-hand side of the equation. This is not a result of reducing the feedstock energy, as we have assumed that the wood input causes net zero emissions. Rather it is due to reduction of the amount of containerboard sent to landfill, and hence reduction in the amount of methane emitted from anaerobic decomposition. However, because of the effects of the variables A and P the result is a little more complex than at first may appear. **Fig. 4** shows a plot of the effect of recycling on emissions, with the other two variables superimposed.

In Fig. 4 the recycling rate runs from zero to 0.8, the limit of technological feasibility, with the present value in Australia being about 0.4. When all material sent to landfill decomposes anaerobically (A=1), recycling reduces emissions considerably. However, when the decomposition is aerobic (A=0), the effect of recycling is much smaller. In fact, when all the wood is produced from continuously renewing plantations recycling actually *increases* emissions. This counter intuitive result comes about because of the emissions arising from the generation of electricity required for mechanical pulping of the recycled material.

These results show that concentrating public policy on aerobic decomposition of waste containerboard might produce better results than concentrating on recycling. Aerobic decomposition (or its equivalent) can be brought about by incineration of waste containerboard, by aerobic composting, or by burning the methane produced in anaerobic decomposition. Only the last of these has any appreciable application in Australia at present, but there is no reason to prevent all three being used when appropriate.

3 Application to Policy Development

This type of systems analysis is useful in demonstrating how LCA can produce results that are relevant to the development and implementation of policy strategies designed to minimise the environmental burden resulting from the provision of services or the manufacture, use and disposal of products within the economy, because:

- it identifies the point(s) in the life cycle of a product or service where the most significant quantities of GHG emissions are generated;
- it indicates which mix of policy options is most desirable (in the case of containerboard one would encourage recycling, replanting of trees, and disposal of waste containerboard by incineration, or aerobic composting, or in landfills in which methane emissions are burnt);
- it provides a quantifiable basis for comparison with other products or services.

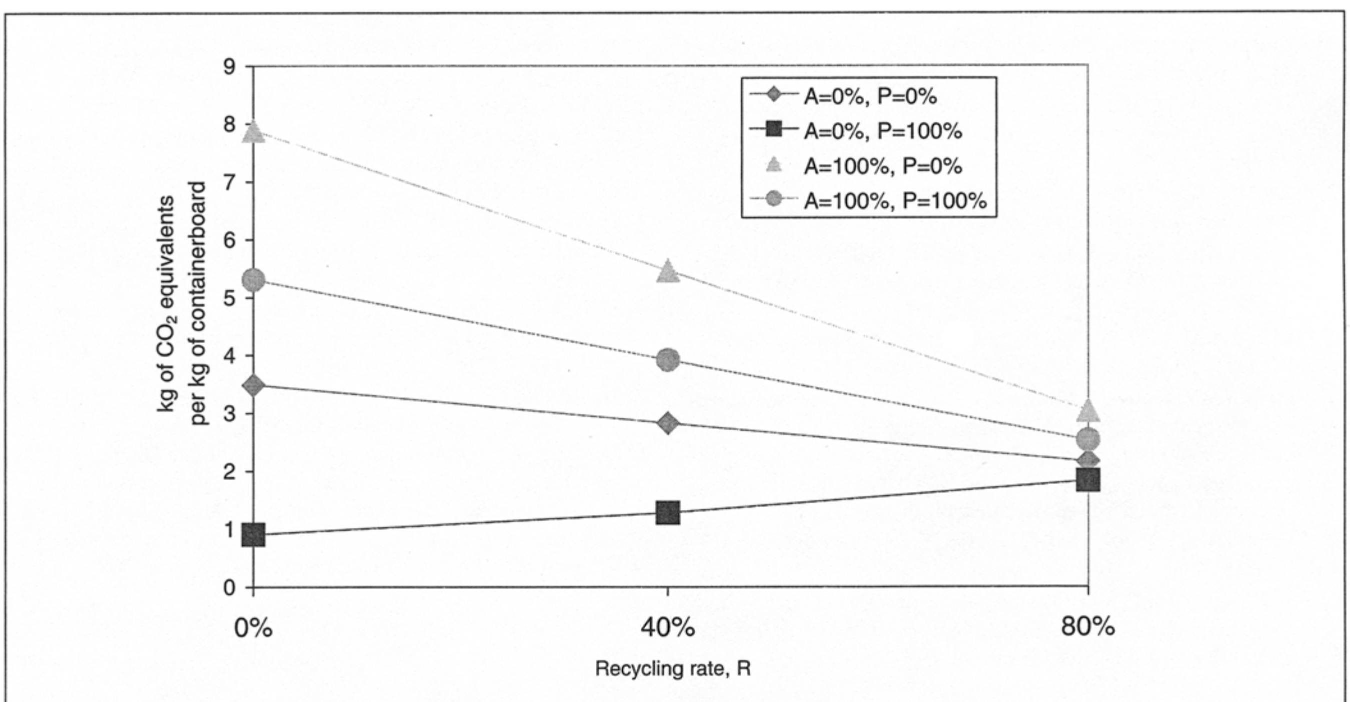

Fig. 4: Sensitivity of emissions to assumptions made

This study has demonstrated that LCA is a useful tool for analysing the GHG emissions attributable to a product or service. This is because all components of the life cycle are examined, including resource extraction, manufacturing, use, transport and disposal. The GHG emissions for each step indicate where improvements are most needed, and their aggregation into a single emission value allows comparisons with other goods and services. Proposed modifications to particular components of the life cycle can then be modelled to determine whether a system change is desirable or undesirable from a greenhouse perspective.

Although this was only a single case study, we could expect that the advantages of LCA demonstrated here would also apply to other products and processes, at least with respect to the assessment of policy options for global environmental effects. This is because, unlike other environmental assessment techniques, LCA analyses the system-wide implications of a change in policy. Thus it is capable of assessing the trade-off between several policy options implemented at various points in the life cycle and, as was illustrated in the case study, reveal the policy mix that would lead to the most beneficial outcome for the environment.

However, this study only examined trade-offs between policies across the life cycle of a product system for a single environmental effect and ignored potential trade-offs between multiple effects. To avoid selecting a policy strategy that improves the environmental performance of a product system for one impact category at the expense of others, impact assessors need also to include other environmental effects in their assessment.

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